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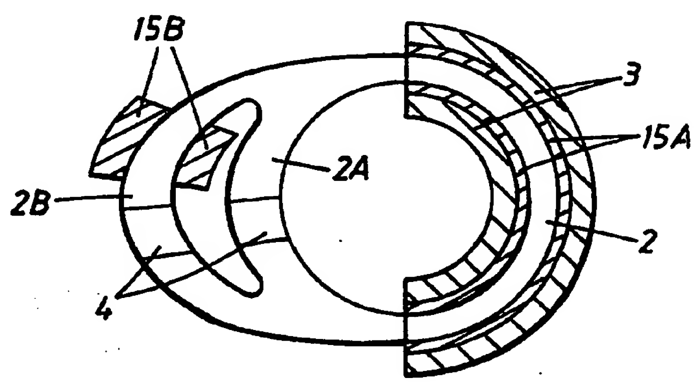
(54) Title: MAGNETIC TAP CHANGER

(57) Abstract

An induction controlled voltage regulator, primarily for high-voltage regulation, includes a magnetic circuit based upon a core (1) having one or more flux paths or legs (2) surrounded by high and low voltage windings (3, 15). The leg (2) is divided in at least two branches (2A, 2B), at least one (2B) of which includes a regulation arrangement with a zone (5) of amendable permeability. The amendment of the permeability may be made by a magnetic rod (4) being movable into and out from the zone (5) formed as an airgap. Another embodiment for such an amendment includes the use of a regulator winding acting on the magnetic flux passing through the leg branch (2B). A compensator winding can be arranged around the leg branch (2B) involving the zone (5) of amendable permeability. The compensator winding is electrically connected in series with capacitor means. At least one of the windings is wound by a high-voltage cable comprising a conductor surrounded by an inner semiconductor, an insulator layer and an outer semiconductor.



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MAGNETIC TAP CHANGER

Technical Field

The present invention relates generally to induction controlled voltage regulators and more particularly, to such an inductance regulation by an electric transformer or reactor means as defined in the preamble of Claim 1. The invention relates also to a regulator winding used by such an induction controlled voltage regulator as defined in Claim 10 and to a method for voltage control in an electrical line or for reactive power control in plants as defined in Claim 13.

Background of the Invention

Conventional induction controlled voltage regulators for lower voltage ranges are arranged by using inductors with coils rotated or shifted in relation to each other as described in the literature, e.g. by I.L. la Cour and K. Faye-Hansen in the book "Drehtransformator und Schubtransformator, Die Wechselstromtechnik Bd. 2, Die Transformatoren", Verlag von Julius Springer, Berlin, Germany, 1936, pages 586 - 598. Furthermore, such an induction control cannot be made for high voltage at reasonable costs. The insulation construction would be a severe design limitation.

Another technique is known from US-A-4 206 434 where the magnetic flux between different legs of an induction controlled voltage regulator is described to be redistributed by a variable DC-magnetization. For this purpose a variable DC-source is needed.

Thus, electric high-voltage control is mostly made by electric transformers involving one or more windings wound on one or more legs of the transformer iron core. The windings involve taps making possible of supplying different voltage levels from the transformer. The present power transformers and distribution transformers as those mentioned above and used in voltage trunk lines involve tap-changers for the voltage regulation. They are subject to mechanical wear and electrophysical erosion due to discharges between contacts. Regulation is only possible in steps. Thus, a stepwise voltage regulation and movable contacts are required for connection with the different taps.

Summary of the invention

The drawbacks of prior art voltage regulation are avoid by the induction controlled voltage regulator according to the present invention. The characteristic features are to be found in that a short length of the flux path or leg of the magnetic circuit surrounded by the high and low voltage windings is divided in at least two branches, where at least one of which includes a regulation arrangement with a zone of amendable permeability.

A favourable embodiment of the inventive regulator has the high-voltage winding wound farthest out for containing all the core flux. The low voltage winding of the regulator is then divided in at least two winding parts, where one winding part comprises the major part of turns and is wound inside the high-voltage winding. The other winding part(s) comprising the minor part of turns, is/are wound around the at least one leg branch having the zone of amendable permeability. The number of turns of the leg branch depends on the required voltage regulation range.

The division of the magnetic flux division necessary between the different leg branches is obtained by changing the reluctance in the different leg branches, which is implemented by the zone of amendable permeability. Different embodiments are possible within the field of the invention. Most preferable embodiments at the moment include either a magnetic rod movable into and out from the zone formed as an airgap, or a regulator winding wound onto a separate magnetic core forming a transverse path to the leg branch involving the zone. The regulator winding is supplied with a control voltage affecting the magnetic flux passing through the leg branch.

The higher reluctance at the airgaps can be compensated for by a compensator winding surrounding the area of said zone and electrically connected in series with a capacitor as a separate closed circuit.

Such a compensator winding loaded with a capacitor forms a negative reluctance $R_C = -n^2 \omega^2 C$. The number of winding turns n and the regulation of the capacitor capacitance C may be chosen in such a way to correspond to the airgap positive reluctance $R_L = l/A\, \mu_0$, where

l is the (eff ctive) length of the airgap,

A is the cross section area of the magnetic core, and

μ_0 is the permeability of air.

Typical values of the capacitance C are in the order of from some microfarads to some millifarads for voltages in the order of 1 kV.

An important condition to make it possible for obtaining such a voltage regulation of high voltages, i.e. 36 kV up to 800 kV, is that at least a part of anyone of the windings mentioned above is constructed of a high-voltage cable which include a conductor, an inner semiconductor, an insulator and an outer semiconductor. Thus, the transformer/ reactor will be of a so called "dry" type. The use of such a designed high-voltage cable makes it possible to "capture" the electric field inside the cable insulation. This means that it is possible to design induction controlled voltage regulators for high-voltage applications.

An additional advantage is that said layers are arranged to adhere to one another even when the cable is bent. Hereby, good contact is achieved between the layers during the cable's entire life.

Different applications lie within the field for the man skilled in the art. Thus, e.g. it is possible to apply the present invention to one-phase induction controlled voltage regulators. Also on-load-tap-changer devices, i.e. a one-phase induction controlled voltage regulator integrated in a transformer, are possible to implement. Furthermore, multi-phase induction controlled voltage regulators can be made with individual phase control as well as with common phase control.

Brief Description of the Drawings

These and other features and advantages of the present invention will become more apparent from the following detailed description of exemplary embodiments thereof, as illustrated in the accompanying drawings, in which:

Fig. 1 is a cross section view of a part of a transformer core according to the invention,

Fig. 2 is a side view of a short part of the transformer core, partly shown in cross section, according to one embodiment of the invention,

Fig. 3 is a side view similar to th one of Fig. 2 but showing anoth r mbodiment of the invention, and

Fig. 4 is a cross-section view of a high-voltage cable being used in the regulation windings according to the present invention.

Detailed Description of the Invention

The invention will now be described in detail with reference to some preferred embodiments, the principle of which is shown in the drawing figures enclosed. Like reference numbers used in the different drawings refer to similar or other equipment having a corresponding function. Figs. 1 and 2 show the part of the voltage regulator only being important to the present invention.

Fig. 1 shows a view of a transformer core 1 of the core flux path or leg 2, half of which being split in two branches 2A and 2B. A high-voltage winding 3 surrounds the unsplit half of the leg 2 in an exterior position, inside which a first part 15A of a low voltage winding is wound around the leg 2. The windings are shown in a cross section view. The first part 15A of the low voltage winding comprises the major part of winding turns and is electrically connected in series with a second part 15B of the low voltage winding. The second part 15B, having a minor part of winding turns, surrounds one 2B of the leg branches.

The voltage regulation of the transformer is based on the principle of changing the magnetic flux Φ linkage in the transformer windings by controlling the reluctance in the different core leg branches 2A, 2B. For that purpose one or both of the core leg branches may include area(s) 4 the permeability of which is decreased and/or increased by a control means.

Fig. 2 shows a favourable embodiment of the invention where a leg 2 of the transformer core 1 is surrounded by the high-voltage winding 3 and the (main) first part 15A of the low voltage winding above, i.e. upstreams of the point where the leg is divided in the two branches 2A and 2B. Just as in the embodiment shown in Fig. 1 the second part 15B of the low voltage winding is wound around the leg branch 2B. This leg branch 2B includes an airgap 5 within which a magnetic rod 4 is arranged. The rod 4 is movable out from and into the airgap 5 as indicated by the double arrow A. The movement of the magnetic rod 4 can be controlled by suitable mechanical means ith r manually or by any lectrical driven means. The result of moving the magnetic rod 4 will be that the flux inside the

second part 15B of the low voltage winding could be changed between zero and full core branch flux. The number of winding turns in the second part 15B of the low voltage winding will limit the regulation area.

As indicated by broken lines in Fig. 2 also the other leg branch 2A may include an airgap 5 with a movable rod 4. Using such movable rods 4 in the two leg branches 2A, 2B may give a more fine regulation of the reluctance in the core 1. The movements of the rods 4 can be made in combination with and directed towards or from each other. The initial position of the rods 4 in the airgaps 5 may be different, e.g. the rod in the leg branch 2B completely fills the airgap (as shown in Fig. 2) while the rod in the leg branch 2A at the same time is in a position more or less outside of the corresponding airgap.

Another embodiment of the invention is shown in Fig. 3, where the mechanical rod and airgap have been substituted by an external magnetic field. Such an external magnetic field may be obtained by a separate magnetic core 9, the axis of which lies in the transverse direction to the leg branch 2B axis. The core 9 can be a premagnetized section or, preferably, a core surrounded by a regulator winding 6. The external magnetic field generated by the regulator winding 6 and/ or by the separate magnetic core 9 counteracts more or less the flux through the leg branch according to the control voltage supplied to the regulator winding 6. The control voltage may be an AC-voltage being in phase with the high voltage to be regulated or, preferably, a DC-voltage. The same induction controlled voltage of the transformer or reactor means is obtained by this embodiment as by those shown in Figs. 1 and 2.

As shown in Fig. 2, a compensator winding 7 is wound around the flux path or leg 2 of the transformer core 1. The compensator winding 7 is forming a close circuit including a capacitor means 8.

The compensator circuit now described can be implemented also in the embodiment shown in Fig. 3.

To make it possible to obtain a regulation of high voltages, i.e. in the field of about 36 through 800 kV, at least one of the windings 3, 6, 7, 15A and 15B, or a part of anyone thereof, is wound by using a high-voltag cabl 61 of a type shown in Fig. 4 as an example.

The cable used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E≤500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any oth r damag , and so that the lay rs are not released from ach

other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Such a high-voltage cable 61 may include one or more electrical conductors 631. The cable embodiment shown in Fig. 4 includes an insulation and the conductor 631 is in direct connection with a first layer 632 having semiconducting properties. The first layer 632 is in turn surrounded by a solid insulating layer 633, which then is surrounded by a second layer 634 having semiconducting properties.

In fig. 4 showing the detail of the invention relating to the cable, the three layers 632, 633, 634 are arranged to adhere to each other even when the cable is bent. The cable shown is flexible, and this property is maintained during the entire life of the cable.

Favourably, the layers 632, 633, 634 are made from the same plastic material or other materials having the same coefficient of expansion. By that, the important advantage is obtained in that deficiencies, cracks, etc. are avoided at thermal movement in the winding. The plastic material of the first and second layers 632, 634 has an electric conductive material added thereto.

Though the present invention has been described above with reference to transformers or reactors shown in the drawings as a single-phase version it is obvious that it also can be applied to multiphase transformers and similar apparatuses, e.g. in autotransform rs and in booster transform rs.

CLAIMS

1. An induction controlled voltage regulator, particularly a transformer or a reactor means, comprising a magnetic circuit involving a core (1) with at least one flux path or leg (2), being surrounded by high and low voltage windings (3, 15), said regulator being **characterized** in that a short length of said at least one leg (2) being divided in at least two branches (2A, 2B), where at least one of which has a regulation arrangement (4 or 6) including a zone (5) of amendable permeability, and in that at least one of the turns of the high-voltage winding (3) is wound by a high-voltage cable (61) including a conductor (631), an inner semiconductor (632), an insulator (633) and an outer semiconductor (634).

2. A regulator according to claim 1, and further **characterized** in that said the high-voltage winding (3) is wound farthest out containing all the core flux and in that the low voltage winding (15) is divided in at least two winding parts (15A, 15B), where one winding part (15A) comprises the major part of turns and is wound inside the high-voltage winding (3) and the other winding part (15B), comprising the minor part of turns, is wound around said at least one leg branch (2B) having the said zone (5) of amendable permeability.

3. A regulator according to claim 1 or claim 2, and further **characterized** in that said zone (5) of amendable permeability includes a magnetic rod (4) being movable into and out from the zone (5) formed as an airgap.

4. A regulator according to claim 1 or claim 2, and further **characterized** in that said zone (5) of amendable permeability includes a regulator winding (6) wound onto a separate magnetic core (9) forming a transverse path to the said at least one leg branch (2B) and being supplied with a control voltage for controlled amendment of the magnetic flux passing through the said at least one leg branch (2B).

5. A regulator according to any preceding claim, and further **characterized** by a compensator winding (7) surrounding the area of said zone (5) with amendable permeability, and electrically connected in series with a capacitor means (8).

6. A regulator according to any preceding claim, and further **characterized** in that also at least one of the further windings (6, 7, 15A, 15B) is wound by a high-voltage cable (61) including a conductor (631), an inner semiconductor (632), an insulator (633) and an outer semiconductor (634).

7. A regulator according to any preceding claim, and further **characterized** in that said regulator is a multiphase transformer, the said at least one leg branch (2B) of each phase includes a regulation arrangement (4 or 6) for independent regulation of each phase.

8. A regulator according to any of the claims 1 - 6, and further **characterized** in that said regulator is a multiphase transformer, the said at least leg branch (2B) of each phase includes a regulation arrangement (4 or 6) being connected for having a joint regulation.

9. A regulator according to any of the claims 1 - 6, and further **characterized** in that said regulator is an autotransformer or a booster transformer.

10. A regulator according to any preceding claim, and further **characterized** in that said layers (632, 633, 634) are arranged to adhere to one another even when the cable is bent.

11. A regulator winding (6) for an induction controlled voltage regulator, particularly a transformer or a reactor means comprising a high-voltage winding (3) and low voltage windings (15A, 15B), according to any of the preceding claims, **characterized** in that at least one of said windings (3, 6, 15A, 15B), or a part of anyone thereof, is wound by a high-voltage cabl (61) including a conductor (631),

an inner semiconductor (632), an insulator (633) and an outer semiconductor (634).

12. A winding according to claim 11, further **characterized** in that said semiconductors (632, 634) and said insulator (633) have the same coefficient of expansion.

13. A winding according to claim 11 or 12, further **characterized** in that said semiconductors (632, 634) and said insulator (633) are made from the same plastic material, the semiconductors plastic material having electric conduction material added.

14. A method for voltage control in an electrical line and/ or for reactive power control in plants comprising at least a transformer or a reactor having at least one of its windings, or a part of anyone thereof, being of a high-voltage cable type according to any of the preceding claims, where the voltage control is effected by an induction regulation changing the magnetic flux linkage in the windings in such a way that the reluctance of different leg branches of said transformer/reactor is changed.

15. A method according to claim 14, **characterized** in that said induction regulation is obtained by the moving a magnetic rod out from or into an airgap within at least one of said different leg branches.

16. A method according to claim 14, **characterized** in that said induction regulation is obtained by variation of a regulation voltage supplied to a winding wound around a regulation leg of said transformer/reactor.

17. A method according to claim 16, **characterized** in that said variation of the regulation voltage is obtained by control of a capacitor having a controllable capacitance.

Fig. 1

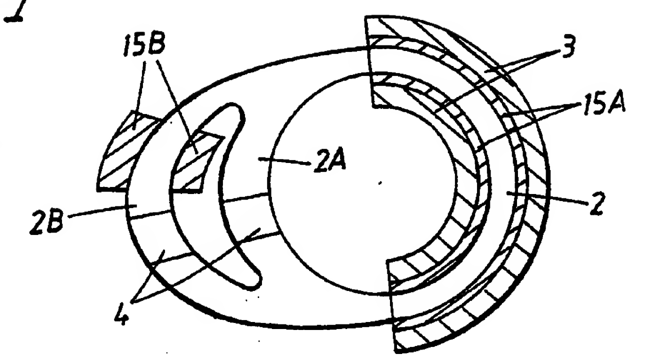

Fig. 2

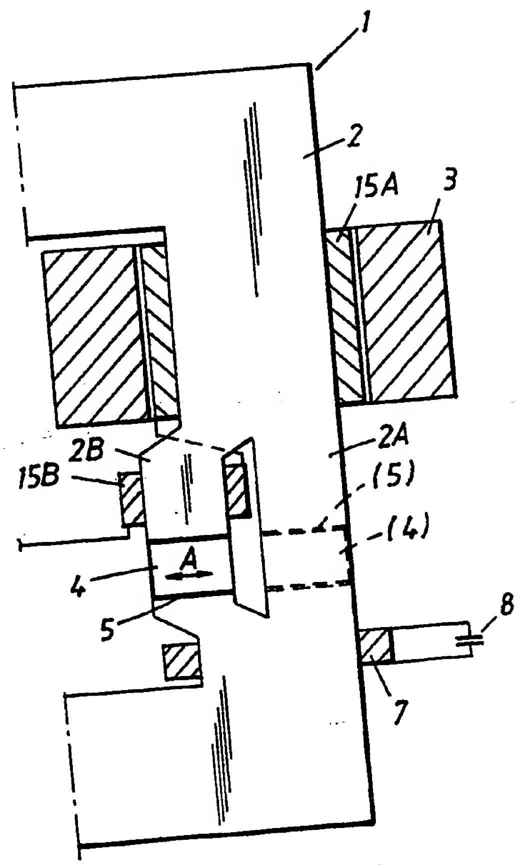

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Fig.3

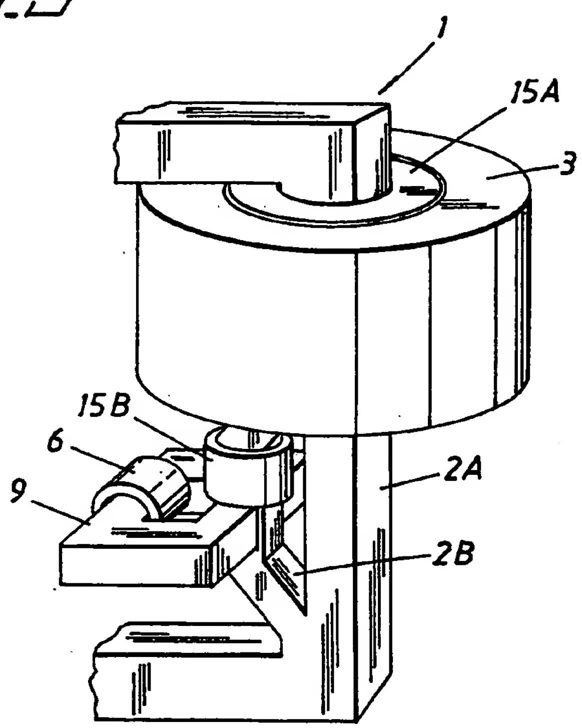

Fig.4